Computerized adaptive testing of psychological factors: relation to upper-extremity disability

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Abstract: BACKGROUND: Psychological factors are important mediators of the differences between impairment and disability. The most commonly used measures of disability and psychological factors are lengthy and are usually administered as paper questionnaires. The aim of this study was to assess the correlation between perceived disability and psychological factors with use of the user-friendly, web-based Patient Reported Outcomes Measurement Information System initiative, and to compare its correlation with a frequently used, paper-based, pain self-efficacy questionnaire. METHODS: A cohort of 213 patients completed a web-based version of the abbreviated version of the Disabilities of the Arm, Shoulder and Hand questionnaire (QuickDASH), the pain self-efficacy questionnaire, the Patient Reported Outcomes Measurement Information System-based computerized adaptive testing Pain Interference questionnaire, and the Patient Reported Outcomes Measurement Information System-based computerized adaptive testing Depression questionnaire. Bivariate and multivariable analyses measured the correlation of these psychological measures with QuickDASH. RESULTS: There was large correlation between QuickDASH and the Pain Interference computerized adaptive testing (r = 0.74; p lt; 0.001), between the Pain Interference computerized adaptive testing and the pain self-efficacy questionnaire (r = -0.72; p lt; 0.001), and between QuickDASH and the pain self-efficacy questionnaire (r = -0.76; p lt; 0.001). The Depression computerized adaptive testing showed a medium correlation both with QuickDASH (r = 0.37; p lt; 0.001) and with the Pain Interference computerized adaptive testing (r = 0.40; p lt; 0.001). The best multivariable model for QuickDASH included the Pain Interference computerized adaptive testing, prior treatment received, and smoking, and accounted for 57% of the variability. Fifty-one percent of the variability in the QuickDASH was explained by pain interference alone. CONCLUSIONS: Maladaptive responses to upper-extremity pain are accurately measured by the relatively user-friendly Patient Reported Outcomes Measurement Information System-based computerized adaptive testing questionnaire. LEVEL OF EVIDENCE: Prognostic Level II. See Instructions for Authors for a complete description of levels of evidence.

DOI: https://doi.org/10.2106/JBJS.L.01614

Menendez, Mariano E; Bot, Arjan G J; Hageman, Michiel G J S; Neuhaus, Valentin; Mudgal, Chaitanya S; Ring, David (2013). Computerized adaptive testing of psychological factors: relation to upper-extremity disability. Journal of Bone and Joint Surgery. American Volume, 95(20):e1491-e1496.
DOI: https://doi.org/10.2106/JBJS.L.01614

Computerized Adaptive Testing of Psychological Factors: Relation to Upper-Extremity Disability

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Background: Psychological factors are important mediators of the differences between impairment and disability. The most commonly used measures of disability and psychological factors are lengthy and are usually administered as paper questionnaires. The aim of this study was to assess the correlation between perceived disability and psychological factors with use of the user-friendly, web-based Patient Reported Outcomes Measurement Information System initiative, and to compare its correlation with a frequently used, paper-based, pain self-efficacy questionnaire.

Methods: A cohort of 213 patients completed a web-based version of the abbreviated version of the Disabilities of the Arm, Shoulder and Hand questionnaire (QuickDASH), the pain self-efficacy questionnaire, the Patient Reported Outcomes Measurement Information System-based computerized adaptive testing Pain Interference questionnaire, and the Patient Reported Outcomes Measurement Information System-based computerized adaptive testing Depression questionnaire. Bivariate and multivariable analyses measured the correlation of these psychological measures with QuickDASH.

Results: There was large correlation between QuickDASH and the Pain Interference computerized adaptive testing ($r = 0.74$; $p < 0.001$), between the Pain Interference computerized adaptive testing and the pain self-efficacy questionnaire ($r = -0.72$; $p < 0.001$), and between QuickDASH and the pain self-efficacy questionnaire ($r = -0.76$; $p < 0.001$). The Depression computerized adaptive testing showed a medium correlation both with QuickDASH ($r = 0.37$; $p < 0.001$) and with the Pain Interference computerized adaptive testing ($r = 0.40$; $p < 0.001$). The best multivariable model for QuickDASH included the Pain Interference computerized adaptive testing, prior treatment received, and smoking, and accounted for 57% of the variability. Fifty-one percent of the variability in the QuickDASH was explained by pain interference alone.

Conclusions: Maladaptive responses to upper-extremity pain are accurately measured by the relatively user-friendly Patient Reported Outcomes Measurement Information System-based computerized adaptive testing questionnaire.

Level of Evidence: Prognostic Level II. See Instructions for Authors for a complete description of levels of evidence.

Musculoskeletal disorders are the most common cause of physical impairment, disability, and ongoing pain[1-3]. The relationship of symptoms and disability to pathophysiology is strongly mediated by psychosocial factors[4]. Indeed, such factors are usually stronger predictors of symptoms and disability than objective physical impairment[5-12].

The most common measures of disability and psychological factors are lengthy and can be burdensome for study subjects[13]. In addition, patient-reported outcomes are usually administered in a paper format, which is particularly cumbersome for both patients and researchers[14]. A recent study conducted by Shervin et al. demonstrated the potential advantages of decreased cost, less respondent burden, and more reliable data collection when administering computer-based questionnaires in a busy orthopaedic outpatient clinic[15]. To further decrease participant burden and error, the current trend in clinical research is to reduce the number of questions to those that are most sensitive and clinically relevant. Previous research revealed

Disclosure: None of the authors received payments or services, either directly or indirectly (i.e., via his or her institution), from a third party in support of any aspect of this work. One or more of the authors, or his or her institution, has had a financial relationship, in the thirty-six months prior to submission of this work, with an entity in the biomedical arena that could be perceived to influence or have the potential to influence what is written in this work. No author has had any other relationships, or has engaged in any other activities, that could be perceived to influence or have the potential to influence what is written in this work. The complete **Disclosures of Potential Conflicts of Interest** submitted by authors are always provided with the online version of the article.

TABLE I Patient Demographic Characteristics (N = 213)

Parameter	Value
Age* *(yr)*	51 ± 17 (19 to 84)
Duration of education* *(yr)*	16 ± 3.1 (9 to 30)
Duration since pain onset* *(mo)*	11 ± 23 (0.2 to 128)
Sex†	
Female	94 (44.1)
Male	119 (55.9)
Visit type†	
First	84 (39.4)
Follow-up	129 (60.6)
Prior surgery†	
Yes	50 (23.5)
No	163 (76.5)
Other pain conditions†	
Yes	59 (27.7)
No	154 (72.3)
Smoking status†	
Yes	22 (10.3)
No	191 (89.7)
Marital status†	
Single	74 (34.7)
Living with partner	13 (6.1)
Married	96 (45.1)
Separated or divorced	19 (8.9)
Widowed	11 (5.2)
Diagnosis†	
Sprain, dislocation, or mallet finger	16 (7.5)
Hand fracture	29 (13.6)
Wrist fracture	29 (13.6)
Amputation, crush, or laceration	19 (8.9)
Carpal tunnel or cubital tunnel syndrome	22 (10.3)
Osteoarthritis	16 (7.5)
Trigger finger	18 (8.5)
Nonspecific arm pain	11 (5.2)
Elbow fracture	12 (5.6)
Shoulder fracture	3 (1.4)
All other diagnoses	38 (17.8)
Working status†	
Full-time	101 (47.4)
Part-time	25 (11.7)
Homemaker	1 (0.5)
Retired	44 (20.7)
Unemployed, able to work	14 (6.6)
Unemployed, unable to work	16 (7.5)
Workers' Compensation	10 (4.7)
Currently on sick leave	2 (0.9)

*The values are given as the mean and the standard deviation, with the range in parentheses. †The values are given as the number of patients, with the percentage in parentheses.

TABLE II Outcome Scores (N = 213)

Instrument	Outcome Scores*
QuickDASH	37 ± 23 (0 to 91)
Pain Interference CAT	58 ± 8.4 (39 to 76)
Pain self-efficacy questionnaire	45 ± 15 (0 to 60)
Depression CAT	48 ± 9.3 (34 to 77)

*The values are given as the mean and the standard deviation in points, with the range in parentheses.

that the use of concise item banks yields similar results in a reduced questionnaire completion time, accompanied by both a higher completion rate[16,17] and a decreased inaccuracy rate[18].

In an attempt to address these issues, the National Institutes of Health (NIH) fostered the Patient Reported Outcomes Measurement Information System (PROMIS)[13,19], a program of research designed to develop standardized item banks to assess patient-reported outcomes relevant across diverse medical fields[20-23]. Through an innovative computerized adaptive testing (CAT) system based on item response theory, only relevant items are selected on the basis of previous responses[20-23]. The potential for error is reduced and confidence in the respondent's score increases as supplementary items are administered[24]. CAT will stop administering items once either the standard error drops below a certain level, or the respondent has reached the maximum number of questions, set at twelve[22,24]. The minimum number of items that need to be answered to get a score is four[24]. CAT filters items that are overly redundant or either too easy or too difficult for the respondent, thus ultimately leading to efficient, meaningful, and precise assessment of patient-reported outcomes with less disruption of clinic flow than would be caused by a longer, paper-based questionnaire[22,25,26]. However, reducing items in a questionnaire has the downside of losing redundancy of items, which has psychometric value[27].

The aim of this study was to evaluate the correspondence between the novel PROMIS Pain Interference CAT questionnaire and QuickDASH (the abbreviated version of the Disabilities of the Arm, Shoulder and Hand [DASH] questionnaire), a frequently employed and validated instrument in upper-extremity illness that measures perceived disability[28-31]. Our null hypothesis is that there is no correlation between the PROMIS Pain Interference CAT and QuickDASH in patients with hand and upper-extremity illness. The secondary null hypothesis is that there is no correlation between QuickDASH and PROMIS Depression CAT, between the pain self-efficacy questionnaire and PROMIS Pain Interference CAT, and between the pain self-efficacy questionnaire and QuickDASH.

Materials and Methods

Study Design

After approval of our institutional review board, 225 new or follow-up patients presenting to one of three orthopaedic hand surgeons, two of whom (D.R. and C.S.M.) were authors in our study, were asked to enroll in this prospective

TABLE III Correlation of the Measures (N = 213)

Measures	Correlation*	P Value
Pain Interference CAT and QuickDASH	0.74	<0.001
Pain Interference CAT and pain self-efficacy questionnaire	−0.72	<0.001
Depression CAT and QuickDASH	0.37	<0.001
QuickDASH and pain self-efficacy questionnaire	−0.76	<0.001
Pain Interference CAT and Depression CAT	0.40	<0.001

*The values are given as the Pearson correlation coefficient.

study. Inclusion criteria were patients who were fluent in English and who were eighteen years of age or older. Our institutional review board required that we exclude pregnant patients. The study was performed during July and August 2012. Twelve patients (5.3%) declined participation, which left 213 patients in the study. Informed consent was obtained from each subject prior to enrollment.

All 213 patients completed a web-based version of the following four questionnaires, in this order: (1) PROMIS Pain Interference[24], (2) PROMIS Depression[21], (3) the pain self-efficacy questionnaire[18], and (4) QuickDASH[31,32]. Both PROMIS questionnaires (Pain Interference and Depression) were administered applying CAT. Unlike instruments with a fixed set of items, CAT offers a dynamic selection of the best items for each participant, based on previous answers[26]. As a result, CAT enables the administration of individually tailored questionnaires with fewer items, consequently leading to reduced questionnaire burden[33,34], while maintaining reliability, generalizability, and validity[33,34]. During the evaluation, patients were asked to complete demographic information. All questionnaires were completed with use of an electronic tablet. Data were collected and were administered with use of Assessment Center, a secure web-based resource promoted and built by the PROMIS initiative[35] (http://www.assessmentcenter.net). The interested reader can try out the PROMIS CAT on the Assessment Center web site.

Patient Characteristics (Table I)

There were ninety-four women and 119 men with a mean age of fifty-one years (Table I). Diagnoses were determined by the treating surgeon; two (D.R. and C.S.M.) of the three treating surgeons were authors in this study.

Outcome Measures

The PROMIS Pain Interference is a computerized adaptive instrument used to measure the degree to which pain limits or interferes with patients' physical, mental, and social activities[24]. PROMIS Pain Interference CAT is not disease-specific, but generic[24]. Using CAT, patients' responses determine the computer's choice of subsequent items from the full forty-one-item question bank[22,24]. Even though items differ across respondents, scores are comparable across participants. A score of 50 points is equal to the mean score for the United States general population, with one standard deviation represented for every 10 points above or below 50 points[24]. A higher score represents more of the outcome being evaluated[24]. In this case, a higher score represents a higher level of pain interference[24].

To illustrate the Pain Interference CAT, we have a sample query and responses from a patient. To the question "In the past seven days, how much did pain interfere with your day-to-day activities?" the patient answered "somewhat." To the question "In the past seven days, how much did pain interfere with your ability to participate in social activities?" the patient answered "quite a bit." To the question "In the past seven days, how much did pain interfere with your enjoyment of social activities?" the patient answered "quite a bit." To the question "In the past seven days, how much did pain interfere with work around the home?" the patient answered "somewhat." These answers resulted in a score of 64 points, indicating that the level of pain interference in this particular patient is worse than 89% of the population.

The PROMIS Depression questionnaire is a computerized adaptive instrument to determine depressive symptoms; it includes measures of negative mood (sadness, guilt), views of self (worthlessness, self-criticism), social cognition, and decreased positive affect and engagement[21]. To take confounding factors into account when evaluating patients with comorbid physical conditions, somatic symptoms such as sleep disturbance and loss of appetite are not included[21]. It is generic, rather than disease-specific[21]. Utilizing CAT, patients' answers determine the computer's choice of subsequent items from the full twenty-eight-item question bank[21]. Identical to the PROMIS Pain Interference CAT, the number of items administered ranges from four to twelve[21]. Although items may be discrepant across respondents, scores are comparable across participants[21]. Consistent with the PROMIS Pain Interference score, the standardized mean score is 50 points and higher scores represent more symptoms of depression[21].

QuickDASH consists of eleven items that assess upper-extremity-related disability[28,31,32]. By only retaining the clinically sensible and relevant content, the QuickDASH yields similar results to the full DASH in a shorter completion time[31]. The overall test score ranges from 0 (no disability) to 100 points (most severe disability); if there is more than one missing item, the test score is invalid[21,28,32]. Items are answered on a 5-point Likert scale.

The pain self-efficacy questionnaire is a validated instrument to assess patient-reported self-efficacy, which is the confidence that people with ongoing

TABLE IV Bivariate Statistical Analysis for the Pearson Correlation (N = 213)

	QuickDASH		Pain Interference CAT		Pain Self-Efficacy Questionnaire		Depression CAT	
Pearson Correlation	R Value	P Value	R Value	P Value	R Value	P Value	R Value	P Value
Age	−0.065	0.34	−0.18	0.009	0.079	0.25	0.002	0.98
Education	0.23	0.001	−0.24	<0.001	0.28	<0.001	−0.054	0.43
Months since pain onset	0.071	0.30	0.068	0.33	−0.083	0.23	0.14	0.039
Pain Interference CAT	0.74	<0.001	—	—	−0.72	<0.001	0.40	<0.001
Depression CAT	0.37	<0.001	0.40	<0.001	−0.50	<0.001	—	—
QuickDASH	—	—	0.74	<0.001	−0.76	<0.001	0.37	<0.001
Pain self-efficacy questionnaire	−0.76	<0.001	−0.72	<0.001	—	—	−0.50	<0.001

TABLE V Bivariate Statistical Analysis for the T Test (N = 213)

	QuickDASH		Pain Interference CAT		Pain Self-Efficacy Questionnaire		Depression CAT	
T Test	T Value	P Value	T Value	P Value	T Value	P Value	T Value	P Value
Prior treatment	−2.3	0.024	−1.2	0.22	0.85	0.39	−0.38	0.71
Sex	1.1	0.29	0.33	0.74	−1.2	0.22	1.9	0.063
Other pain conditions	−2.8	0.006	−3.2	0.001	4.1	<0.001	−2.9	0.004
Prior surgery	−0.97	0.33	−0.26	0.79	1.0	0.31	−1.3	0.20
Smoking status	−2.9	0.005	−1.2	0.24	3.5	0.001	−1.9	0.062

pain have in being able to perform numerous activities while in pain[18]. It consists of ten items measured with 7-point Likert scales, ranging from 0 ("not at all confident") to 6 points ("completely confident"), and the score is calculated by adding the items[18]. One patient missed one question on the pain self-efficacy questionnaire; therefore, we inserted the average score of the patient's other questions for this missing item.

Statistical Analysis

An a priori power analysis indicated that a minimum sample size of 193 patients would provide 80% statistical power ($\alpha = 0.05$) to detect a 0.20 correlation strength between the QuickDASH and the PROMIS Pain Interference questionnaire. To correct for a possible 10% loss to follow-up or incomplete responses, 213 patients were enrolled.

We assumed normality on the basis of the large sample size. Continuous data were presented in terms of the mean, the standard deviation, and the range. Categorical variables were presented with frequencies.

Bivariate and multivariable analyses were performed. In bivariate analysis, the correlations between the four patient-reported outcomes (QuickDASH, Pain Interference CAT, Depression CAT, pain self-efficacy questionnaire) with continuous variables (age, years of schooling, months since pain onset) were analyzed with use of Pearson correlations. Associations with dichotomous variables were examined with the independent samples t test and one-way analysis of variance (ANOVA) for categorical variables.

Variables that either were significant ($p < 0.05$) or satisfied the criteria for entry ($p < 0.10$) were inserted in a backward, stepwise, multivariable linear regression analysis to assess their ability to explain the variation in the QuickDASH score. Before performing the multivariable linear regression, we created dummy-coded variables for categorical variables with more than two categories. We planned to use the Pain Interference CAT, but not the pain self-efficacy questionnaire in the multivariable analysis, because they both measure the same coping strategy. The multivariable regression model produced the adjusted R-squared value, which reflected the percentage of the overall variability that could be accounted for by the variables included in the model for the QuickDASH.

Source of Funding

No funding was received in support of this study.

Results

Outcome Scores

The mean QuickDASH score was 37 points (Table II) and the correlation between the measures is shown in Table III.

Bivariate and Multivariable Analysis

In a bivariate analysis, there was significant association between the QuickDASH and the Pain Interference CAT, Depression CAT, and pain self-efficacy questionnaire with regard to working status, education, smoking, other pain conditions, and prior treatment received (Tables IV, V, and VI). The pain self-efficacy questionnaire was considered redundant with the Pain Interference CAT and we excluded the scores on the pain self-efficacy questionnaire from multiple linear regression analysis. The final model for QuickDASH included the Pain Interference CAT, prior treatment received, and smoking, and explained 57% of variability, with the Pain Interference CAT being the factor with the most influence on arm-specific disability (partial R-squared = 0.51).

TABLE VI Bivariate Statistical Analysis for the One-Way ANOVA (N = 213)

	QuickDASH		Pain Interference CAT		Pain Self-Efficacy Questionnaire		Depression CAT	
One-Way ANOVA	F Value	P Value	F Value	P Value	F Value	P Value	F Value	P Value
Diagnoses	1.2	0.28	1.8	0.061	1.2	0.26	1.3	0.23
Working status	3.6	0.001	3.5	0.001	9.5	<0.001	3.6	0.001
Marital status	0.52	0.72	1.8	0.12	0.40	0.81	0.83	0.51
Specific hand surgeon	0.78	0.46	0.91	0.91	0.29	0.75	0.16	0.85

Discussion

Our null hypothesis was refuted: there was a large correlation between the PROMIS Pain Interference CAT and QuickDASH in patients with hand and upper-extremity illness. Pain interference was the strongest predictor of self-assessed arm-specific disability, accounting for over half of the variability in QuickDASH scores.

The strong influence that pain interference exerted on disability (51%) is in line with other studies conducted in patients with elbow trauma[5,8]. Although they were able to account for the lesser part of variability, Doornberg et al.[5] and Lindenhovius et al.[8] noted that pain was the strongest predictor of patient-rated measures of upper-extremity disability, explaining 36% and 41% of the variability, respectively. Numerous other studies have also elucidated the pivotal role that pain and illness behavior play in upper-extremity disability[6,7,9,11,36-38].

The importance of this study lies in the innovative paradigm used for patient-reported outcomes assessment in upper-extremity conditions. Recently, CAT has been successfully applied to evaluate psychological factors in other fields of medicine[34,39] but has not been used frequently in an outpatient orthopaedic hand and upper-extremity setting. The results in our study are promising, as the administration of PROMIS-based CAT questionnaires provides improved precision due to individually tailored questionnaires with fewer items[33,34,40]. Furthermore, the use of these novel instruments could lead to a decreased questionnaire burden and a substantial reduction of sample size requirements[33]. We found that PROMIS Pain Interference CAT required an average number of five items to generate immediately available online scores. However, the pain self-efficacy questionnaire, a static questionnaire with a fixed set of items, required five more questions than the Pain Interference CAT. The pain self-efficacy questionnaire (−0.76) and Pain Interference CAT (0.74) both had a large correlation with the QuickDASH, but, in our opinion, the Pain Interference CAT seemed preferable to both respondents and clinical researchers because of the dynamic individually tailored questionnaire requiring half the number of items, and an immediately available score after questionnaire completion that can be compared with population norms.

Depression, assessed with use of the PROMIS-based CAT questionnaire, had medium correlation with QuickDASH scores. Our data agree with the findings of a medium-strength correlation between upper-extremity self-assessed disability and depression as shown in the studies of Vranceanu et al.[30] ($r = 0.49$) and Ring et al.[10] ($r = 0.44$). However, in contrast with these studies[10,30], multivariable analyses showed that depression was not an independent predictor of perceived disability.

Several shortcomings of the study should be kept in mind to better interpret our data. First, we did not calculate the average time to complete each of the four questionnaires. By doing so, we would have been able to determine if there was a difference in completion time between the pain self-efficacy questionnaire and the Pain Interference CAT; however, the average number of items administered using the Pain Interference CAT was half of those using the pain self-efficacy questionnaire, so it is highly likely that the Pain Interference CAT's completion time is shorter. Second, all of the patients included in our study lived in the United States; therefore, we were not able to assess culture-related discrepancies in perceived disability. Previous research has revealed that the country of residence may be a factor to take into consideration when explaining variability in perception of health status[41].

Other psychological measures on PROMIS include: Anger, Anxiety, Fatigue, Pain Behavior, and Emotional Support. PROMIS also has a Physical Function CAT and is piloting separate upper and lower-extremity measures. Future research will determine the utility of these measures for patients with upper-extremity illness.

We have piloted the use of the PROMIS Pain Interference and Depression measures as talking points with patients. In particular, the Assessment Center can generate a graph that shows where a patient falls on population norms. We have told patients, "You are able to manage your symptoms now, but if you moved up the scale a bit, it would mean that you would have much less pain and you would be able to do more." This type of feedback with respect to pain interference worked well, but there is such a stigma associated with depression that we found patients less receptive to feedback about the depression measure. Some patients asked more about these aspects of their recovery and others accepted it without comment and we proceeded to the next step. For many patients with musculoskeletal conditions, improved mood and mindset are their best option to increase health and well-being[8,10-12,18,36]. There is growing evidence that depression and ineffective coping strategies affect recovery from treatment as well, but as long as we only look at the percentage of "successful" results in uncontrolled studies, we may only be looking at the percentage of patients for whom our treatment gave permission to be healthy at least for a while (the placebo effect).

We conclude that the Pain Interference CAT and the Depression CAT are two valid questionnaires for evaluating psychological factors in patients with hand and upper-extremity illness. The widespread adoption of PROMIS-based CATs can potentially lead to a reduction in not only respondent and researcher burden, but also in sample size requirements and ultimately study costs. Money is saved in part on paper, printing, and storage, but primarily by not having to pay for an assistant to transfer the data to an electronic format. In our study, activity-related pain interference was responsible for the majority of the variability in the disability. Depression had a medium correlation with disability, but was not retained in the multivariable model. These strong and consistent findings suggest that interventions to optimize mood, to lower pain interference, and to decrease catastrophic thinking and symptoms of depression have the greatest potential to decrease musculoskeletal symptom intensity and magnitude of disability. ■

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